

Iridium Reflectivity Calibrations in the Region 50-1100 eV for the AXAF Telescope Mirror

D.E. Graessle¹, R.L. Blake¹, A.J. Burek¹, J.J. Fitch¹, E.M. Gullikson², R. Soufli¹ and A. Stonas³,

¹ Smithsonian Astrophysical Observatory,
60 Garden Street, Cambridge, Massachusetts 02138, USA

² Center for X-ray Optics, Ernest Orlando Lawrence Berkeley National Laboratory,
University of California, Berkeley, California 94720, USA

³ Oxford Research Group,
5737 Clinton Avenue, Richmond, California 94805, USA

INTRODUCTION

In December 1998 NASA will launch the Advanced X-ray Astrophysics Facility (AXAF) into earth orbit for the next generation studies of radiation from cosmic x-ray sources, in the energy range 0.1-10 keV. For the past seven years our team at the Smithsonian Astrophysical Observatory has been conducting a program to calibrate the reflectivity of the x-ray telescope mirrors, so that the observed intensities may be converted to an absolute scale required for quantitative scientific analysis. The program has been carried out on synchrotron beamlines, where witness flats, coated simultaneously with the telescope mirrors, are measured for reflectivity as a function of energy and angle of incidence over the range of energies and angles that are applicable to the telescope in orbital observations¹. In July 1996 we obtained our first beamtime at the ALS beamline 6.3.2, which allows us to calibrate the mirrors over the range 50-1100 eV that is not available to us elsewhere. Beamline 6.3.2 not only covers the needed energy range, but also has a reflectometer built into the end position². It was sufficient to make a revised sample holder for our AXAF mirror samples and to adapt a foil holder for transmission samples that we use to augment the determination of optical constants. Witness flats (samples) consist of glass optical substrates that have been coated with about 100 Å of Cr and 330 Å of Ir - the reflecting surface for the telescope. During the coating process, these flats were located either along the locus of the AXAF mirror element surface (qualification coating runs), or just off the ends of the AXAF mirrors (production coating runs). Since the curved telescope mirrors will have some figure errors and roughness variations over their surfaces, both of which cause differences in reflectivity, it is necessary to determine the optical constants of the Ir coatings from the calibration data and subsequently derive the AXAF mirror efficiency by a complex modeling process. We report here the results of our third run on beamline 6.3.2, in July 1997.

MEASUREMENTS

Two types of measurements are required to completely characterize each witness sample. First, one measures the reflectivity versus angle at some energy where the beam can penetrate deeply enough into the Ir-Cr layers to make the reflectivity sensitive to the layer thicknesses. Then, the reflectivity versus angle shows interference oscillations at large grazing angles. The Fresnel equation, which gives the reflectivity versus angle from electromagnetic theory, may then be used to adjust the Ir and Cr layer thicknesses until the measured oscillations best match the calculated ones. Simulations showed that the best sensitivity is at the higher energies on this beamline. Fig. 1 (left) shows measured data for a particular sample. One can see that the oscillations at reflectivities below 1% have a distinctive pattern. The details of this pattern determine the Ir and Cr layer thicknesses, while the average amplitude versus angle determines the sample roughness. The second type of measurement required is the reflectivity versus angle, at closely spaced energies over the entire range of operation of the mirrors. This permits application of the Fresnel equation at each energy to derive the Ir optical constants from fits to the data. The reflectivity varies strongly with energy, especially in the vicinity of x-ray absorption edges. Furthermore, the

AXAF mirror elements have one of four fixed grazing angles, each less than one degree. It is therefore more relevant to measure the reflectivity versus energy at selected angles. From earlier runs we have been able to determine an optimum choice of angles for each energy sub-range between 50 and 1400 eV. We try to achieve an approximately uniform distribution of steps in reflectivity between 10% and 100% by choice of angles in each energy sub-range. Therefore, the angles may not be the same from one sub-range to the next. Table 1 lists the angles and the optimized beamline parameters for each sub-range.

Energy Range (eV)	Grating (lines/mm)	Order Sorter (mirror, angle in deg)	Filter	Grazing Sample Angles (deg)	# of energy steps
50-72	300	C, 10	Al	0.864, 3, 6, 11, 15, 19, 23, 27, 35	88
66-100	300	C, 14	Si	0.864, 3, 6, 11, 15, 19, 23, 27, 35	68
94-112	300	C, 8	Be	0.864, 3, 6, 11, 15, 19, 23, 27, 35	36
107-187	300	C, 6	B	0.864, 1.5, 2.5, 4, 6, 9, 12, 15, 20	40
181-285	600	Ni, 8	C	0.696, 1.33, 2, 3, 4, 5, 6, 7.5, 9, 12	52
260-454	600	Ni, 6	Ti	0.614, 0.864, 1.33, 2.2, 3, 3.8, 4.5, 6, 7.5, 9, 10.5	194
440-574	1200	Ni, 6	Cr	0.614, 0.864, 1.33, 2, 2.7, 3.4, 4.2, 5.2, 6.5, 8	134
558-778	1200	none	Co	0.614, 0.864, 1.33, 2, 2.7, 3.4, 4.2, 5.2, 6, 7	220
752-932	1200	none	Cu	0.614, 1, 2, 2.7, 3.4, 4.1, 4.8, 5.6, 6.3	90
900-1400	1200	none	none	0.614, 1, 2, 2.7, 3.4, 4.1, 4.8, 5.6, 6.3	50

Table 1. Measurement parameters for the Ir mirror calibrations at the ALS beamline 6.3.2. The monochromator grating chosen for each energy region is indicated in the 2nd column. A filter (4th column) is used in order to block second harmonic wavelengths and scattered light from the monochromator; in upcoming measurements, a Mg filter will be used for the energy range 900-1300 eV. Furthermore, a triple-reflection low-pass filter (order sorter, 3rd column) is used for suppression of higher harmonics.

TENTATIVE RESULTS

Partial results for a particular sample are shown in Fig. 1 (right) for the lowest four energy sub-ranges and part of the fifth. A measure of beam purity and freedom from systematic errors is the overlap of reflectivities between segments for different sub-ranges. From Table 1 the grazing angle of 6° is seen to be common to all five of the energy subranges plotted in Fig. 1 (right). The overlaps are within the data noise. Of special interest is the region from 50 to 72 eV, where one can see the well defined profiles of the Ir N_{VII} and N_{VI} absorption edges in the reflectivity. Fine scans reveal the convolved presence of the Ir O_{II} edge between the N_{VII} and N_{VI} edges. The amplitude of reflectivity jumps across Ir absorption edges is important because the calibrations can be done in lower resolution, with higher signal to noise ratio, when the jumps are less than 1%. We have the following preliminary results from the data obtained thus far:

- (i) Ir N_{VII} and N_{VI} edges are well observed with large jumps. High resolution scans are required in this energy region.
- (ii) N_V and N_{IV} edges (296.3 and 311.9 eV) are in the vicinity of the C K edge (284.2 eV); the presence of carbon contamination on the witness flats makes it necessary to utilize special procedures for studies in this energy region.
- (iii) N_{III} , N_{II} is a well defined doublet feature requiring fine scans in the region 480-520 eV. Especially the range 440-574 eV requires high resolution due to the Cr underlayer and the presence of oxygen contamination on the samples.
- (iv) N_{II} , N_I , and O_{II} edge regions have reflectivity jumps of less than 1%, thus they may be

scanned in a low resolution mode.

(v) The ranges 94-112, 107-187, 181-285, 752-932, and 900-1400 eV may be scanned with lower resolution and improved signal to noise ratio in future runs.

(vi) Both angle scans at 925 eV and energy scans 558-778 eV may be used in the future to evaluate the Cr and Ir layer thicknesses and simultaneously improve the optical constants of these two elements in the low energy range, especially around the Cr L_{III} , L_{II} edge.

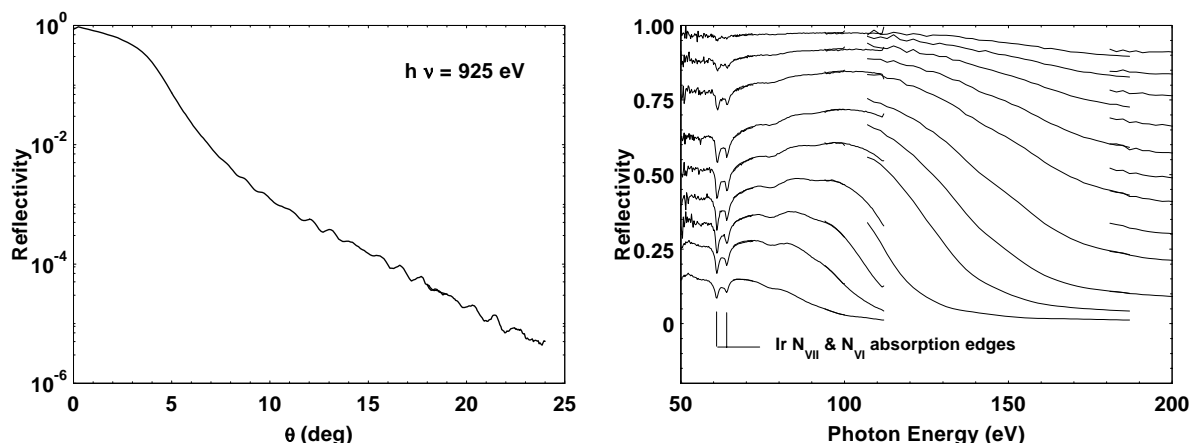


Figure 1. Left: Reflectivity data (shown on a logarithmic axis) versus grazing angle θ (in degrees), from one of the AXAF witness mirrors. This type of measurement aids in the determination of the Cr and Ir layer thicknesses on the mirror. Right: Reflectivity data versus energy at selected angles (see Table 1). Data obtained in five energy sub-ranges within the region 50-200 eV, are shown in this plot. After converting the above data to reflectivity versus angle at each energy point, the optical constants δ , β of the refractive index $n = 1 - \delta + i\beta$ of Ir are derived by means of least-squares curve fitting. Angles in each energy sub-range are selected so as to give a uniform sampling for the curve fitting.

ACKNOWLEDGEMENTS

We thank Jim Underwood for arranging initial beamtime at 6.3.2 to get this program started and for continuing to upgrade the beamline. Thanks to John Cobuzzi and John Bowers for technical assistance. Stan Mrowka was especially generous in his efforts to keep the computers updated and to implement new beamline electrometers.

REFERENCES

1. D. E. Graessle, A. J. Burek, J. J. Fitch, B. Harris, D. A. Schwartz, and R. L. Blake, in *Grazing Incidence and Multilayer X-Ray Optical Systems*, edited by R. B. Hoover and A. B. C. Walker II, (Proceedings of SPIE Vol. 3113, San Diego, CA, 1997), pp. 52-64.
2. J. H. Underwood, E. M. Gullikson, M. Koike, P. J. Batson, P. E. Denham, K. D. Franck, R. E. Tackaberry, and W. F. Steele, *Rev. Sci. Instrum.* **67**, available in CD ROM only.

This work was supported by the US D.O.E. and by NASA under contract number NAS8-40224.

Principal Investigator: Dale E. Graessle, Smithsonian Astrophysical Observatory, 60 Garden Str., Cambridge, MA 02138. Email: graessle@head-cfa.harvard.edu. Telephone: 617-495-7041.